

Controlled-Atmosphere Storage of Potatoes

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PROLONGING the storage life and maintaining the quality of chipping potatoes are problems of direct concern to potato growers and processors in the fall crop areas of northern United States. Growers are interested in storage practices that will minimize the weight loss of potatoes and still provide a salable product. Processors are concerned with obtaining high quality potatoes throughout the year. However, the local supply of good quality potatoes decreases after December and reaches a minimum level during spring and early summer.

Types of potato storages have been largely dependent on the prevailing climate, geographical area, ultimate use of the potato, and established marketing practices (17)*. A satisfactory storage environment should minimize weight losses from respiration and evaporation, retard storage diseases, and maintain a temperature that will have the most favorable effect on other quality factors which are of greatest importance to the processor or consumer. It is evident that considerable variation exists in storage conditions and in storage requirements for potatoes when used for different purposes and stored for different periods of time.

Controlled-atmosphere (CA) storage—where the gaseous atmosphere surrounding a product is controlled at low concentrations of oxygen and higher than normal concentrations of carbon dioxide—has significantly increased the storage life and reduced the deterioration of many biological products, principally apples, by lowering the respiration rate. Due to the importance of potatoes in the Red River Valley and the need for improved storage methods, particularly of chipping potatoes, controlled-atmosphere storage for potatoes was considered. Since chipping potatoes are stored at high temperatures to maintain acceptable chip color, considerable shrinkage and a high incidence of stor-

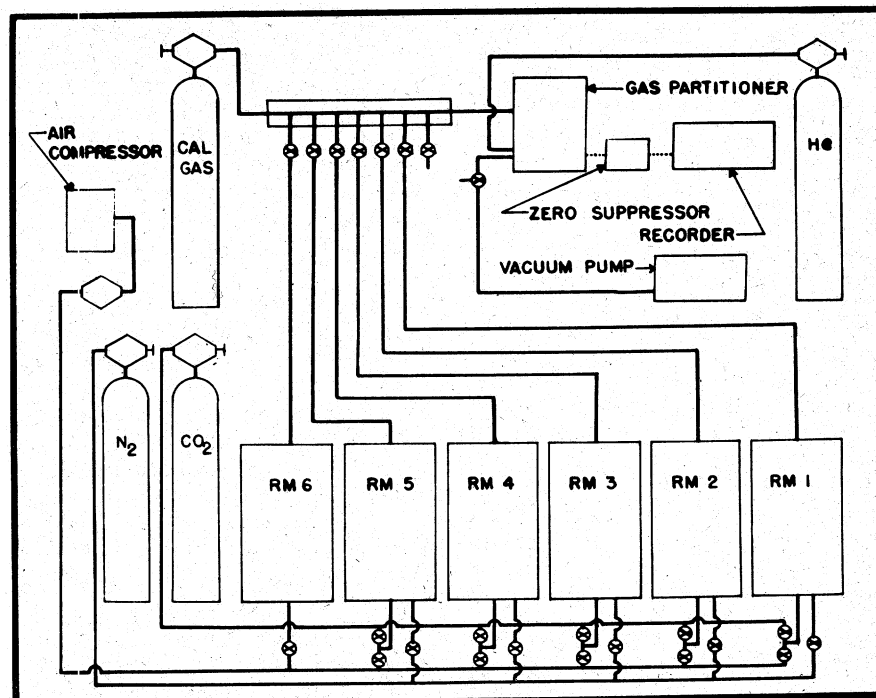


FIG. 1 Schematic of gas-supply system and gas-analysis system.

age diseases are observed as compared to storage conditions for table stock. Controlled-atmosphere storage of chipping potatoes offered the possibility of storing the potatoes at lower temperatures, providing the buildup of reducing sugars could be suppressed.

These investigations were initiated to study the effects of storing potatoes in various concentrations of carbon dioxide, oxygen and nitrogen on chipping quality and storage life.

REVIEW OF THE LITERATURE

Storage Life

If the potato is considered from the consumer's point-of-view, then storage life may be considered to be the time it takes to reach the point at which it becomes unacceptable for consumption. Burton (3) considered shrinkage of the potato to become evident at a 5 percent weight loss; thereafter, potatoes become increasingly unacceptable until at a 10 percent weight loss the potatoes are wrinkled, spongy and very difficult to peel.

Temperature is generally the most important single environmental factor affecting storage life, as it directly affects the rate of metabolic reactions occurring in the potato. It may be theorized that maximum storage life occurs at a temperature at which respira-

tion rate is the minimum. Hopkins (9) found that the minimum respiration rate was at 37.4 F.

The relative humidity of the air, or the vapor-pressure difference between the potato and the surrounding air, also affects storage life. Burton and Hannon (6) found potatoes lose approximately 0.2 percent of their original weight per wk per mm of vapor pressure difference after the initial high-moisture losses subsided. Smith (17) found the weight loss of potatoes over a 7-month period to be approximately 0.5 percent by respiration and 5.7 percent by water loss.

The recommended air-flow rate through potatoes is closely associated with the air temperature and moisture content of the incoming ventilation air. In a study based on Long Island conditions, Sawyer (15) found the optimum ventilation rate to be 0.83 cfm per cwt for best control of black spot, shrinkage and fusarium dry rot. In some Maine studies, Hunter and Toko (10) found the optimum ventilation rate to be 1.2 to 2.4 cfm per cwt for control of soft rot.

Chip Quality

The chief criterion for evaluating potato-chip quality is the resulting color of the chip after processing. This is affected primarily by the concentration

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* Numbers in parentheses refer to the appended references.

of the reducing sugars, principally hexose, in the potatoes at processing time. Shallenberger, Smith and Treadway (16) found that reducing sugars and sucrose react with amino acids to produce brown chips at temperatures used to fry potato chips. Pressey (13) found that sucrose is a reservoir of reducing sugars and may participate in browning only to the extent that it is hydrolyzed to reducing sugars.

As storage temperature decreases, the total sugar content and the reducing sugar content of the potatoes increases. Burton (3) found the total sugar contents to range from 3.19 g per 100g fresh weight at 2 C to 0.46 at 15 C and the reducing sugar contents to range from 1.81 to 0.30 between 2 C and 15 C for Majestic potatoes stored four wks. Smith (18) found that at storage temperatures of 40 F or lower, sprout growth was prevented, but reducing sugars and sucrose accumulated excessively in tubers below 45 F. Tubers may be reconditioned between 60 and 80 F with 70 to 85 percent r.h. to "desweeten" the potatoes. However, reconditioning may cause chip color to vary considerably.

Thornton (20) states that many researchers have experimented with the influence of carbon dioxide on the respiration of plants, seeds and tubers and have found that carbon dioxide has primarily a retarding influence on respiration. Pflug (12) states that the storage life of most products is increased by reducing the oxygen concentration below 10 percent with a maximum benefit normally at 3 to 5 percent and by increasing carbon dioxide to the 3 to 5 percent level.

Smith and Davis (19) studied the chipping quality of potatoes that had been stored under controlled-atmosphere conditions for short periods. Carbon-dioxide concentrations were above 90 percent for several of the tests. Their results showed that high CO₂ to low O₂ atmospheres prevented accumulation of glucose in the tubers. Also, chips were of a highly acceptable light color as compared with those stored at the same low temperature and for the same 5-wk period in air.

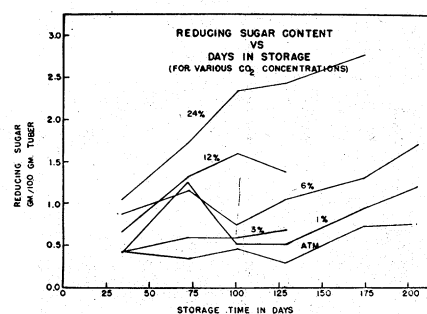


FIG. 2 Reducing sugar content vs. storage time for various CO₂ concentrations during 1964 storage trials.

Pflug (12) studied the chipping quality of potatoes stored under oxygen concentrations less than 6 percent and of carbon dioxide more than 3 percent. He found that the potatoes directly out of controlled-atmosphere storage tended to produce a light-colored chip. The color of the chips from potatoes directly out of controlled-atmosphere storage became darker with increasing time in storage. The combination of 34 F plus controlled-atmosphere storage helped to hold the initial light chip color, but the suppressing effect was quickly overcome after taking the potatoes out of storage.

Burton (4) found sprout growth to be inhibited at 10 C by 15 percent carbon dioxide, decreased by lower concentrations, and stimulated by still lower concentrations. Approximately 2 to 4 percent carbon dioxide appeared to be the optimum concentration for sprout growth. Reducing the oxygen concentration to about 5 percent stimulated sprout growth. Burton (5) found that alcohol vapors suppressed the sprouting of potatoes.

Samotus and Schwimmer (14) found that starch decomposition was lower for potatoes stored in nitrogen than in air.

Denny and Thornton (8) found that the rapid increase in reducing sugar which occurs in potato tubers stored at 5 C was prevented by storing the tubers in a 5 percent carbon dioxide atmosphere. Thornton (20) also found that the reducing sugar content was greatly increased by storage of tubers at 21 C in an atmosphere containing 60 percent carbon dioxide. Barker (1) found that all concentrations of carbon dioxide above 10 percent at 5 and 7.5 C increased the total sugar content. At 1 C total sugar was decreased with 20 percent carbon dioxide, but was accompanied by discoloration and the development of a peculiar odor of the tubers. Thornton (21) found the rate of oxygen uptake by potatoes to be increased as carbon-dioxide concentration increased from 8 to 64 percent.

EQUIPMENT AND PROCEDURES

Kennebec potatoes were stored at 40 F at various CO₂, O₂ and N₂ concentrations during the 1964 and 1965 storage seasons. Samples were removed monthly to determine the condition of the potatoes and for sugar analysis and chipping-quality tests. Additional short-term trials were conducted in 1966 on potatoes stored under 100 percent CO₂, 100 percent N₂, and air to determine the sugar concentrations vs. storage period.

Experimental Equipment

Six gastight containers were constructed of high-density plywood. Covers were bolted onto the containers to

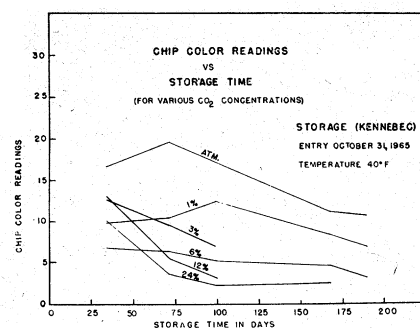


FIG. 3 Chip color readings percent reflectance vs. storage time for various CO₂ concentrations during 1964 storage trials.

facilitate removal of the potato samples. Each chamber held approximately 100 lb of potatoes.

The gas concentrations in the chambers were regulated by manually adjusting needle values in the supply lines of air, carbon dioxide and nitrogen. Air was supplied by a compressor, whereas carbon dioxide and nitrogen were supplied from high-pressure cylinders. The gases flowed continuously through the chambers at low flow rates. Approximately 95 percent relative humidity was maintained in the chambers. Fig. 1 schematically shows the arrangement of gas supply lines and gas analysis equipment.

The gas concentrations were measured by a Model 29 Fisher gas partitioner which employed dual chromatographic columns for the separation of carbon dioxide, oxygen and nitrogen gases. The gases were pulled from the various controlled atmosphere rooms through aluminum tubing and the sampling loop of the partitioner by means of a vacuum pump. A Sargent recorder recorded the peak of the gas concentrations arising from the output signal of the electrical bridge circuit constructed of hot platinum wires in the thermal conductivity cells of the partitioner. A zero suppressor was used to inject a bucking voltage in the circuit whenever a signal output was greater than the range of the recorder. This permitted the electrical peak to be recorded on the recorder even though its value was much greater than the range of the recorder. Calibration of the equipment was conducted each day by sampling a known standard gas and atmospheric air.

The potatoes were placed under controlled-atmosphere storage conditions at the end of October of each year's trial. Prior to being placed in CA storage, the potatoes for both trials have been held at 70 F during the suberization period of one month. For the fall 1964 trial, the potatoes were placed in 10-lb potato bags without being washed or dried and, therefore, carried some surface dirt. For the fall 1965 trials, all

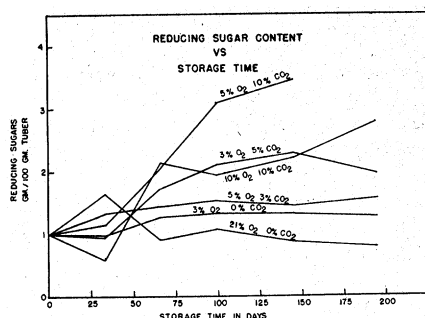


FIG. 4 Reducing sugar content vs. storage time for various gas concentrations during 1956 storage trials.

potatoes were washed and dried prior to placing in 5-lb bags.

Sugar Analysis

The sugar analyses were conducted at the Red River Valley Potato Processing Laboratory, East Grand Forks, Minn. Invertase activity, pH, total sugars, sucrose and reducing sugar concentrations were determined for the 1964 trial. Only total sugars and reducing sugars were determined for the 1965 trials, as they affect chip color more directly than the others.

Chip Processing

Potato samples from each of the rooms were chipped and processed monthly at the Red River Valley Potato Processing Laboratory pilot processing plant. All of the samples were processed at 360 F.

Chip Color

The color of the potato chips was compared with a color reference standard prepared for the Potato Chip Institute International and initially described by Coughlin (7).

Reflectance measurements were also conducted on the potato chips in the Horticulture Department Laboratory, as an objective method for determining potato chip color. The reflectance method and the comparison between standard chip colors and reflectance readings have been described by Isleib (11). The potato chips were ground by a Wiley mill prior to the reflectance tests. The colorimeter was a photo instrument that sensed the reflected light from compressed ground-chip samples. A photovolt reading of 28 or higher indicated acceptable chip color.

Other Tests

During the fall of 1965, gas samples were taken from the storage atmospheres of several commercial storages and from large bins of potatoes at the Red River Valley Potato Research Center at East Grand Forks, Minn. The gas samples were analyzed to determine whether there was a carbon dioxide build-up during the suberization period (or period when little or no air flowed

through the potato pile). The gas samples were taken at various depths and locations in the bins by pulling gas samples through tygon tubing by means of small fans and were collected in sampling tubes. The carbon dioxide, oxygen and nitrogen concentrations were then determined with the previously described gas partitioner.

Storage Trials with Pure Gases

At the Red River Valley Potato Processing Laboratory, some tubers were stored in jars with pure O_2 , N_2 , CO_2 , or air flowing through them at 52 F and 100 percent relative humidity during the 1965 storage season.

During 1966, experiments were conducted to determine the effects of storing potatoes in pure CO_2 , N_2 , and air for short periods. Kennebec potatoes were held at 65 F from harvest to the start of each trial. The potatoes were washed and dried, then placed in storage atmospheres of CO_2 , N_2 , and air at 40 F. Samples of five tubers each were removed from storage and tests were run immediately. The methods of analysis have been discussed by Pressey (13). Invertase and inhibitor were determined as relative values with arbitrary units.

RESULTS

Results will be discussed by years because the controlled-atmosphere storage tests were different for 1964, 1965, and 1966.

1964 Results

The Kennebec potatoes stored at 12 and 24 percent carbon dioxide and 10

percent oxygen deteriorated in quality and appearance much more rapidly than potatoes stored under lesser concentrations of carbon dioxide. Mold growth on the surface of some of the potatoes appeared after the first month of storage in the 12 and 24 percent chambers. In these two chambers very few tubers were of any value at the end of six months of storage, as they had a high incidence of soft rot and black heart. The potatoes stored under 12 percent carbon dioxide and 10 to 15 percent oxygen were near normal in appearance.

Two chambers of potatoes were removed in March and replaced with Kennebec potatoes which had been in conventional storages. The carbon-dioxide concentrations for these potatoes were increased to 90 and 95 percent and maintained there for a two-month period. At the end of the storage period, potatoes in both chambers were very moist on the surface and were beginning to decay. The tubers also had black heart, indicating that they were getting insufficient oxygen.

Reducing Sugar Concentration Analyzing the reducing sugar concentration of the potatoes was the chief means of objectively determining the quality of the stored potatoes. Fig. 2 shows the reducing sugar content of the tubers stored under various carbon-dioxide concentrations as a function of storage time. The reducing sugar concentration in potatoes appeared to be directly related to carbon dioxide concentration and storage time. Significantly higher reducing sugar concentrations were found in samples stored at high carbon

TABLE 1. RESULTS OF STORING KENNEBEC POTATOES UNDER 100 PERCENT CO_2 , 100 percent N_2 , and air at 40 F for varying lengths of time

		Reducing sugar, percent	Total sugar, percent	Weight loss, percent	Invertase		Inhibitor	Chip color
					0 min	10 min		
14 Days								
CO ₂ (100%)	a)	0.13	0.41	1.2	30	53	255	Acceptable
	b)	0.28	0.44	0.7	5	35	245	Acceptable
N ₂ (100%)	a)	0.28	0.75	0.8	35	48	230	Acceptable
	b)	0.24	0.41	0.6	8	60	218	Acceptable
Air	a)	1.00	2.25	0.1	288	455	405	Dark
	b)	1.36	2.75	0.4	230	350	365	Dark
34 Days								
CO ₂ (100%)	a)	0.26	0.38	6.4				Some deterioration Acceptable Acceptable Dark Dark
	b)	0.26	0.38	11.8				
N ₂ (100%)	a)	0.08	0.38	5.4				
	b)	0.18	0.44	0.1				
Air	a)	0.95	1.25	0.1				
	b)	1.00	1.25	0.1				
	pH	Reducing sugar	Total sugar	Weight loss	Invertase			Chip color
					0 min	10 min		
8 Wks								
Starting ^a								
CO ₂ (100 percent)	5.35	0.24 0.26	0.38 0.28	10.1	35 88	185 130		Acceptable Brown, vitrious
N ₂ (100 percent)	5.2	0.13	0.23	7.0	133	150		Brown, vitrious
Air	5.4	0.80	1.00	0.2	50	385		Dark
9 Wks plus 2 wks in air								
CO ₂ (100 percent)	5.4	0.22	0.20	2.7	145	105		Part black
N ₂ (100 percent)	5.8	0.17	0.33	3.4	105	50		Black
Air	5.8	0.86	1.13	0.1	85	308		Dark

* Inhibitor of starting material was 165,215.

dioxide concentrations and as storage time increased.

Chipping Quality Fig. 3 shows the chip color readings as a function of storage time and carbon dioxide concentrations. The results indicated that the light reflectance from the chips was inversely related to carbon dioxide concentration and storage time. Chip colors were too dark to be compared satisfactorily with the color reference standard.

1965 Results

Potatoes stored under lower oxygen and carbon dioxide concentration during the 1965 storage season than for the previous year, had a lower incidence of mold growth and soft rot. Nearly all of the potatoes stored under 5 percent oxygen, 5 percent carbon dioxide and 90 percent nitrogen were sound and similar in appearance to those stored under normal atmospheric concentrations at the end of the storage period. Potatoes, stored at 10 percent carbon dioxide, had a high incidence of surface mold and soft rot regardless of oxygen concentration. The potatoes stored at 10 percent carbon dioxide and 5 percent oxygen were completely deteriorated after 150 days of storage at 40 F.

Reducing Sugar Concentration Fig. 4 shows a plot of reducing sugar concentrations vs storage time for the potatoes stored under various gas concentrations. The potatoes stored at low carbon dioxide percentages had the lowest reducing sugar. Generally the reducing-sugar concentration varied directly with the percent of carbon dioxide. The reducing-sugar concentration for potatoes stored at 3 percent oxygen and 0 percent carbon dioxide was approximately the same as for those stored at atmospheric conditions. The combination of 5 percent oxygen and 10 percent carbon dioxide gave the highest reducing-sugar concentrations with increasing storage time.

Chip Color Fig. 5 shows the chip color reflectance readings vs. storage time for the potatoes stored under various gas concentrations. The lightest colored chips were obtained from the potato samples stored at the lowest percentage carbon dioxide. The darkest chips were obtained from the 5 percent oxygen and 10 percent carbon dioxide stored potatoes. Chip colors did not vary significantly after the first two months of storage. The potato chips at the start of the storage period were darker than normal. The fall of 1965 was extremely cool, which caused higher initial reducing sugar concentrations than normal in the potatoes and, consequently, contributing to darker chip color.

Carbon Dioxide Concentrations in Commercial Storage After observing

that mold growth and soft rot incidence were higher for potatoes stored under high carbon dioxide during the 1964 storage period, it was decided that the carbon dioxide concentrations in commercial storages should be measured. The gas samples taken from the storages showed that carbon dioxide concentration between 3 and 4 percent may occur in certain areas of bins during the suberization phase when the ventilating fans are off. Shortly after the fans were turned on in the through-circulation bins, the carbon dioxide concentration decreased to 0.1 to 0.2 percent. After one month of ventilation the carbon dioxide concentration was around 0.08 percent.

Potato Storage with Pure Gases Storage in water-saturated atmosphere of flowing pure N_2 , O_2 , and CO_2 at 52 F resulted in a breakdown of the tuber in less than two months, with those stored in pure CO_2 breaking down first.

1966 Results

The 1966 results are summarized in Table 1.

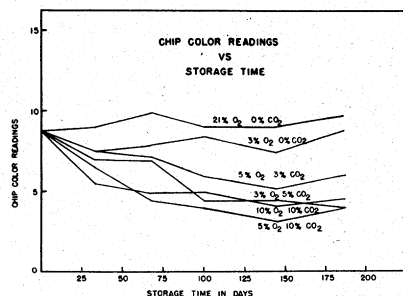


FIG. 5 Chip color readings percent reflectance vs. storage time for various gas concentrations during 1956 storage trials.

DISCUSSION

Based on these experiments where potatoes were stored under various combinations of carbon dioxide, oxygen and nitrogen concentrations, it appears unlikely that controlled-atmosphere storage with these gases will appreciably increase storage life or maintain a high-quality chipping potato over those stored in conventional storages over long periods of time. Potatoes stored above 10 percent carbon dioxide had a high incidence of surface mold, soft rot and black heart. Even potatoes stored under lower carbon dioxide and lower oxygen concentrations at 40 F had higher reducing sugar concentrations and, consequently, darker chip color than those stored at atmospheric concentrations.

These results indicate that controlled-atmosphere storage of Kennebec potatoes causes darker potato chips, as compared with results obtained by Pflug (12) and Smith and Davis (19). Pflug found that a combination of 34 F plus controlled-atmosphere storage at low

oxygen and low carbon dioxide concentrations helped to hold the initial light chip color determined immediately out of storage. However, he found the potato chip color became darker with increasing storage time which is in agreement with the results of this investigation. Smith and Davis found that high carbon dioxide (up to 90 percent) and low oxygen concentration storage for periods up to 7 wks produced light color chips. Our results showed that the reducing sugar concentrations nearly doubled during the first month of storage and the chips became darker for potatoes stored above 90 percent carbon dioxide. The 1966 results confirmed the work of Smith and Davis (19) in that sugars do not accumulate when potatoes are stored in high CO_2 concentrations. However, deterioration of the potatoes was evident at approximately 14 days and the chips were dark at the end of 8 wks. The weight losses, presented in Table 1, are indicative of the amount of deterioration of fresh potatoes.

Barker and Saifi (2) found that tubers were likely to develop injury as an after-effect if held in nitrogen for longer than 12 days. Their results were similar for potatoes stored under low oxygen concentrations. They found the hexose concentrations to remain nearly constant throughout the 12 days in nitrogen, but it increased very rapidly after the potatoes were returned to air. The carbon-dioxide production and sucrose concentration decreased with time during the 12-day storage in nitrogen, but increased rapidly after returning to air and reached peaks in about 3 days in air. During the after-effect period, the carbon-dioxide production and sugar concentrations remained higher for the next 30 days than for those potatoes stored in air throughout the test period. The results of the 1966 trials confirm the results of Barker and Saifi and of Samotus and Schwimmer (14) in that storage of potatoes in 100 percent nitrogen results in low sugars and deterioration of raw potatoes in 14 days.

Some of the results of this investigation, as well as those of Pflug and of Smith and Davis, may be explained by the results of the basic studies of Barker, of Burton and of Thornton. First, potatoes may deteriorate rapidly after 12 days of storage under low oxygen concentrations or anaerobic conditions. This was observed in the potatoes stored in carbon dioxide concentrations above 90 percent and with oxygen concentrations less than 5 percent. Second, the sugar concentrations may be lowered within the 12-day period by storage in low oxygen atmospheres. This may explain why the studies by Pflug and by Smith and Davis indicate that chips processed immediately on removal of

the potatoes from controlled-atmosphere storage were lighter colored. Our results indicate that chip color became darker with increasing storage time which substantiates Pflug's results. It appears likely that the storage of potatoes under near-anaerobic conditions for less than 12 days may improve chip color slightly if the potatoes are processed within a few hrs after removal from storage. Third, carbon dioxide may have a dual effect on the metabolic reactions of potatoes where some reactions are stimulated below 7 or 8 percent and others are inhibited above this level. This is apparently true for the mechanisms regulating sprout growth (4, 22). However, the results of this investigation did not show any dual effect on the level of reducing sugars or on chip color.

The invertase level indicated that this protein is not synthesized under anaerobic conditions. This may account for the low levels of reducing sugars as explained by Pressey (13). The data is insufficient to fully explain the levels of inhibitor and protein. The low total sugars imply that the mechanism for the formation of all sugars is inhibited. The similarity of results with CO₂ and N₂ indicate that the mechanism is the same: the absence of O₂ is a causative agent.

Based on the results of this experiment and of others, it appears that controlled-atmosphere storage of potatoes may possibly be used only for extremely short storage periods of not over 12 days under very low oxygen concentrations. Then the potatoes would have to be chipped immediately on removal from storage before the repressive effect is overcome to obtain light-colored chips. For longer storage periods at low oxygen and low carbon dioxide levels, the results indicate the potatoes would have to be reconditioned in order to obtain acceptable light-colored chips. No increase in storage life or quality was evident for long-term controlled-atmosphere storage as compared with conventionally stored potatoes.

SUMMARY AND CONCLUSIONS

Kennebec potatoes were stored at 40 F at various CO₂, O₂, and N₂ concen-

trations during the 1964 and 1965 storage seasons in gas-tight containers constructed of high-density plywood. Gases were supplied to each chamber from an air compressor and high-pressure cylinders of CO₂ and N₂. The gas concentrations in the chambers were measured by a gas partitioner employing chromatographic columns for separation. The various gas concentrations in each chamber were obtained by manually adjusting needle valves in each supply line.

Samples of potatoes were taken monthly from the chambers for potato-chip processing and sugar analysis. Potato chip color was determined objectively by reflectance readings with a photovolt instrument sensing reflected light from compressed ground-chip samples.

Results of storing potatoes under controlled-atmosphere conditions indicated: (a) storage life was not increased by long-term storage of potatoes with low oxygen and low or high carbon dioxide conditions, (b) incidence of mold growth and soft rot was higher as carbon-dioxide concentration increased, (c) reducing sugar concentration increased and chip color became darker as carbon-dioxide concentration increased, (d) reducing sugar concentrations and chip colors for potatoes stored at 3 percent oxygen and 0 percent carbon dioxide were nearly the same as for potatoes stored at normal atmospheric concentrations of 21 percent oxygen and 0 percent carbon dioxide and (e) carbon dioxide concentrations in commercial storages reached 3 to 4 percent when fans were off over extended time periods, but this concentration was not high enough to promote a high incidence of mold growth or soft rot.

In conclusion, long-term, controlled-atmosphere storage of potatoes with lower oxygen and higher carbon dioxide concentrations than normal atmospheric concentration was not effective in prolonging storage life and in maintaining high-quality potatoes for chipping. Short-term storage up to 12 days under nearly anaerobic conditions may give lighter colored chips if the potatoes are processed immediately on removal from storage.

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